NAVAL HEALTH RESEARCH CENTER

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SUMMARY

Problem

Early and accurate intervention for medical emergencies sustained on the battlefield, in chemical/biological warfare environments, or while rendering humanitarian service is critical to saving lives and limiting long-term disability. Head traumas and multiple injury cases are particularly complex to treat. Optimum emergency care requires improved training for first responders and military medical personnel. Conventional training techniques, such as classroom instruction and field exercises, and noncombat experience acquired in the hospital contribute to the learning process, but have innate drawbacks and limitations. As a result, the inexperienced provider may suffer in performance when faced with limited supplies and the demands of stabilizing casualties never encountered back home in the resource-rich hospital setting. Training could be significantly improved if trainees had the opportunity to repeatedly practice on virtual patients using immersive, dynamic case simulations and could experience the consequences of their assessment and treatment decisions.

Objective

The objective of this project was to develop a virtual reality training system that would provide immersive, three-dimensional (3D) graphical training opportunities for teaching emergency response skills to medical providers. The simulation tool would provide a virtual environment in which trainees could see, hear, and interact with simulated casualties. The system would simulate both the dynamic state of the patient and the results of trainee intervention, allowing the trainee to perform diagnoses and interventions and to receive immediate feedback (in the form of changing patient symptomatology) on the trainee's assessment and triage decisions.

Approach

We selected a training approach employing experiential, problem-based learning. The system was designed to provide a clinically accurate, dynamic environment engaging the user and facilitating the acquisition of emergency decision-making skills in high-stress, resource-constrained settings. Representative cases emphasizing important teaching points were identified. Subject matter experts developed clinical algorithms for these cases using a simple mathematical model, the Finite State Automata (FSA), for casualty simulation. The FSA depicted the succession of physiological changes occurring in the patient as a result of the natural course of the trauma; specific actions initiated to treat the patient, both optimal and suboptimal; the absence of treatment; and the passage of time.

Results

A modular training capability was developed by adapting and refining preexisting multimedia personal computer and virtual reality systems. In this project, the server and user interfaces were developed into separate modules. This enabled one case simulation to be presented to different types of user interfaces. The final system included five components: (1) a tool for authoring simple trauma cases, (2) the FSA-based case algorithms, (3) the server with resident data files and algorithm-based code, (4) a two-dimensional multimedia flat screen trainer, and (5) a 3D

virtual reality trainer incorporating devices for immersive viewing ("goggles"), for tracking the trainee's position and posture, and devices enabling the trainee to manipulate virtual objects.

Conclusions

In this project, collaborators adapted existing technology to produce flexible, modular virtual reality and PC-based trainers for teaching cognitive assessment and treatment skills. The system allows users to follow different assessment and treatment paths and witness the consequences of their decision-making. Trainees watch a virtual patient either deteriorate (and without intervention, ultimately succumb) or stabilize as a result of the quality and timeliness of those decisions. Users can practice repeatedly without putting patients at risk until cognitive skills are mastered. The training systems can be deployed to the field and used to maintain those skills once acquired.

Abstract

Rapid and effective intervention for medical emergencies sustained on the battlefield, while rendering humanitarian service, or in a chemically/biologically contaminated environment is crucial for saving lives and limiting long-term disability. Inexperienced providers may suffer in performance when faced with limited supplies and the demands of stabilizing casualties never encountered back home in the comparatively resource-rich hospital setting. Head trauma and multiple injury cases are particularly complex to diagnose and treat, requiring the integration and processing of complex multimodal data. In this project, collaborators adapted and merged existing technologies to produce a flexible, modular patient simulation system with both three-dimensional virtual reality and two-dimensional flat screen user interfaces for teaching cognitive assessment and treatment skills. This experiential, problem-based training approach engages the user in a stress-filled, high-fidelity world, providing multiple, tailored learning opportunities within a compressed period of time and without risk. The system simulates both the dynamic state of the patient and the results of user intervention, enabling trainees to watch the virtual patient deteriorate or stabilize as a result of their decision-making speed and accuracy. Systems can be deployed to the field enabling trainees to practice repeatedly until their skills are mastered and to maintain those skills once acquired.

BACKGROUND

Medical readiness is critical to saving lives and returning troops to duty. The fast-paced, dynamic environments of modern operations can make the delivery of emergency care even more difficult than in the past. Because troops can be highly dispersed and very mobile, casualties may occur in scattered pockets of the battlefield, be harder to locate, and require more extensive treatment from infantrymen or corpsmen while awaiting evacuation. Rapid and effective treatment in such scenarios is even more crucial. This puts greater pressure on the responder, underscoring the importance of providing the most effective and efficient medical training possible.[1,2]

Head trauma presents a difficult emergency situation with far-reaching implications. The assessment and stabilization of head trauma patients constitute a complex process further complicated by the ever-present reality of inadequate patient histories, diagnostic modalities, and logistic support. Of all the combat casualties that occur, head injuries are among the most costly and permanently debilitating. Death, permanent disability, and the emotional, social, and economic consequences are profound. The monetary cost of severe head traumas is staggering, with an estimated cost to the civilian sector of $83.5 billion per year.[3]

Early identification and appropriate treatment may significantly influence the outcome of head injuries. Helling and colleagues found that early surgical intervention in patients with cranial gunshot wounds seemed to result in better survival, and they predicted that even the severely wounded might benefit from aggressive early treatment.[4] Early recognition of secondary injuries that may follow the initial event and worsen the brain injury can improve clinical outcome. Hypoxia, hypercapnia, hypotension, and intracranial hypertension are factors that can cause secondary insults to the brain. Prevention of these factors begins in the field and continues up to and during hospitalization. A major goal of the responder is to prevent these secondary injuries from occurring.[5] Early and continued evaluation and tracking of injuries to identify trends ensures more informed triage decisions and thus a more optimal distribution of limited health care resources to those patients who will most benefit. It is important, therefore, to have accurate models to predict clinical outcome from head injury within a short time after the injury is sustained.[3]

At issue is how to teach these sophisticated emergency response skills to corpsmen and medics, as well as to nonmedical combat personnel who will first encounter casualties on the battlefield. Such complicated, dynamic decision-making requires training that realistically simulates the perceptual overload and stressors these responders must manage. First responders seldom have acquired firsthand experience with these types of injuries. Their predeployment training is usually limited to classroom and field exercise modalities where direct observation of the clinical impact of injuries and interventions is absent. Training could be significantly improved if trainees had the opportunity to practice in fully immersive, dynamic case simulations and could experience the consequences of their assessment and treatment decisions.

To address this need we merged a personal computer (PC)-based simulation system capable of incorporating detailed sets of assessment, treatment, and patient response algorithms with three-dimensional virtual reality (3-D VR) technology. The resulting system teaches clinical decision-making skills by interactively presenting simulated patients to trainees. Simulating the dynamic state of the patient as a function of elapsed time, the clinical course of each trauma, and the results of treatment, the system allows trainees to perform assessments and interventions and to receive immediate feedback (in the form of changing patient signs and symptoms) on the consequences of the diagnostic and treatment decisions made. This system thus incorporates an experiential, problem-based training approach, critical for effectively assimilating decision-making skills.

Problem-based, Experiential Learning

The rationale underlying simulation training draws from the concepts of both experiential and problem-based learning (PBL). Experiential learning is a situation in which the student is directly in touch with the realities being studied. This learning mode gained credence beginning with John Dewey in the 1930s and is founded on the premise that human development occurs as a function of experience—we learn by trial and error, and that the results of such learning can be reliably measured. Innovative experiential programs have proliferated in the form of internships, field placements, structured exercises, and game simulations. Experiential learning provides the critical link between the classroom and the real world, to enhance and supplement traditional classroom and textbook education.[6]

PBL was first used in medical education at McMaster University in the late 1960s and is now widely used as an instructional method where patient problems serve as a context for students to learn problem-solving skills and acquire basic and clinical science knowledge. In PBL, the case scenarios do not initially provide all the information needed to solve the problem, thereby providing greater realism and raising compelling issues for new learning.[7] PBL models can mimic the conditions inexperienced first responders will encounter—emergencies for which they may be untrained and unfamiliar.

Proponents of experiential, problem-based, and contextual learning theories suggest that such instruction is more nurturing and engaging[6]; that student attendance, attitude, mood, and motivation is consistently more positive[8,9]; that students learn better when actively involved and interested in the task and when material is presented in a clinically relevant way[10]; that these methods promote increased retention of knowledge[8,9] and deeper learning (surface-level vs. deep-level processing) than conventional teaching methods[10,11]; and such instruction may enhance transfer of concepts to new problems.[10] Computer-based training has advanced experiential, problem-based training technology to levels unimaginable before the advent of the microchip.

Simulation Technology

Computer-based technology coupled with PBL is revolutionizing the domains of medicine and medical training. Normal human anatomy, modeled by the National Library of Medicine's The Visible Human Project, stores cross-sectional data representing a normal adult male and female so that users can manipulate and display complex 3D images of anatomic structures.[12] Disease pathogenesis modeling and simulation are providing new avenues for understanding and treating disease.[13-16] Simulations are becoming an integral part of how we now teach and test medical providers.[17] The National Board of Medical Examiners (NBME®) and the Federation of State Medical Boards have incorporated computer-based patient simulations into the United States Medical Licensing Examination™. NBME also plans to add case simulations to the current battery of examinations they make available to medical schools throughout the country.[18]

Computer technology is increasingly making headway in the military medical training domain. Historically, medical operational readiness has relied on conventional training techniques such as classroom instruction and field exercises using actors with moulage (realistic

make-up of injuries), and on hospital-acquired noncombat experience. These each contribute to the learning process, but also have innate drawbacks and limitations. As a result, the inexperienced provider may suffer in performance when faced with limited supplies and a barrage of casualties never encountered back at home in the comparatively resource-rich hospital setting.

Computer-assisted instruction can successfully meet unique training requirements,[19] assist corpsmen with the triage and stabilization of casualties in remote environments,[20] and provide trainees with a cost-efficient, user-friendly training modality.[21] The application of modeling and simulation techniques has been used effectively for personnel training.[22] Zajtchuk and Sullivan suggested that computer-generated simulations of the human body can and should be used to integrate medical training with operational battlefield requirements, to provide a near-seamless transition from medical training to clinical practice.[23] Interactive-based instruction can give a user immediate feedback, thus providing a mechanism for iteratively improving performance.

Simulation training offers a more highly advanced and effective way to teach and rehearse[24] and is especially useful for high-stress medical disciplines like emergency medicine,[25] civilian disaster,[26] and battlefield casualty care.[27] A longstanding component of aviation training, simulation technology is now used in the nuclear power industry and has more recently been adapted by anesthesiology departments to teach the principles of crisis management.[28,29]

Trauma Simulation Systems

A variety of trauma simulation systems have been developed for use in the civilian and military sectors. Simulated patients can be represented by moulaged actors or by standardized patients,[30] or electronically presented two-dimensionally on a flat screen, three-dimensionally as immersive VR (employing sight, sound, and tactile feedback), or in the form of a responsive, computer-driven mannequin. Simulation training offers distinct advantages. These systems:

- Let trainees practice responses with no risk of death or injury to a patient.
- Present repeated training of specific scenarios.
- Simulate rarely occurring phenomena that might not otherwise be observed by the trainee in his or her normal routine.
- Augment traditional medical instruction.

- Provide refresher training to ensure skill maintenance.
- Allow the reconstruction of clinical events.
- Let teams practice hands-on crisis resource management.

Various types of 3D VR systems and their application for teaching and assessing clinical skills have been well described by Kaufman and Bell at Dalhousie University in Canada:

> A new technology known as 'Virtual Reality' has tremendous potential to assist medical educators in teaching and assessing clinical skills of students, residents and physicians in practice. Virtual Reality consists of a computer-generated three-dimensional simulation in which the user both views and manipulates the contents of the environment. Various degrees of immersion may be experienced that may include elements such as vision, touch or sound. It can provide an environment that so closely represents an actual clinical situation that skills learned will transfer to patients. Many variations in anatomy or other complications can be presented, and trainees can practice hundreds of times until their skills are perfected.[31]

Healthcare Computing Publications periodically features reviews of medical simulation systems, including advanced cardiac life support programs and online resources.[32] The Air Force has developed a specific prototype system, the Virtual Emergency Room, that provides scenario-specific training for mobile military field hospital teams.[33] Kizakevich et al. have created the Virtual Medical Trainer prototype that uses a multimedia flat-screen interface with sound and graphics to teach the cognitive skills required for prehospital assessment and stabilization.[34]

The Military Medical Training and Evaluation system was used by the Navy in Kernel Blitz-'95 and '97 as a mission scenario-driven system for recording and evaluating the performance of trainees. Students attended a succession of moulaged actors simulating casualties. Each clinical case was represented by an algorithm containing sequences of observations, strategic decision points, task-time-resource processes, and clinical outcomes. Case algorithms have been developed for a variety of cases, including trauma, disease and nonbattle injuries, humanitarian, nuclear, biological, chemical/medical complications, and nursing interventions.[35]

A computer-driven mannequin, used at both the University of Ottawa Heart Institute[36] and at Bethesda, Maryland's Uniformed Services University of the Health Sciences,[37,38] physically reacts to instructions from software manipulated off stage by an instructor. The mannequin is driven by physiological models running in real time that respond to the clinical intervention of the trainee. In these hands-on sessions, trainees can administer drugs from syringes with ID

microchips on each tip, read vital signs using real medical equipment, observe patient movement and respiratory function, and listen to heart and breath sounds via stethoscope. The student can try different clinical paths and compare outcomes. The instructor can tailor the rate of patient degradation to suit the needs of the student, can insert various clinical complications to broaden the learning experience, and can pause the session at any time for discussion, correction, and didactic training.

Antecedent Technologies Integrated for this Project

This work built on two existing capabilities. Sandia National Laboratories (SNL), in Albuquerque, New Mexico, had created a prototype VR simulation (MediSim) of patients injured in a field environment to address the training of first responders, including battlefield medics and corpsmen.[39] Tekamah Corporation, in conjunction with USUHS, had developed as the foundation of their CD-ROM Exercise Generator (EXGEN) system, assessment and treatment algorithms for traumas sustained in various combat and civilian emergency scenarios. Since head trauma is difficult to differentially diagnose and treat, we thought it would be particularly beneficial for first responders to train on a system that integrates the multiple cue presentation capability of VR and the assessment and treatment strength of EXGEN technology. The VR interface with its head-mounted display (VR "goggles"), immersive synthetic environment, and interactive paradigm, would allow the trainee to visualize the casualty model and to perform diagnoses and medical interventions. Sets of assessment, treatment, and patient response algorithms—derived from the simpler EXGEN model—would drive the interactive casualty model that provides the VR system with the symptoms, physiology, behaviors, and responses displayed by the simulated patient.

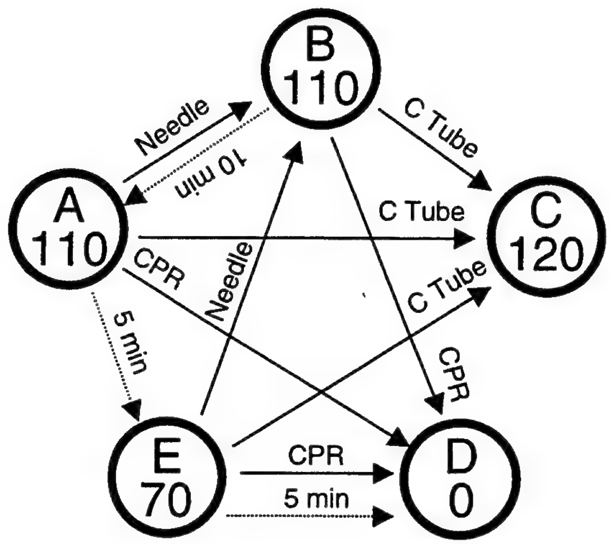
Tekamah's algorithm-based technology was first demonstrated at the July 1995 National Guard and Reserve medical exercise, Operation Arch Angel.[40,41] Known as the Medical Readiness Learning Initiative (MERLIN), this PC-based trauma care tutor presented a sequence of static cases to the trainee for evacuation prioritization, assessment, and treatment and it scored performance against an expert treatment path.[42] MERLIN algorithms were then expanded and bundled into EXGEN, later renamed MEDREX (Medical Readiness Exercises), the forerunner to this project's client-server system.

SNL had previously developed BioSimMer (Biocontamination Simulated Medical Emergency Response), a VR-based tool for teaching medical defensive countermeasures in chemical/biological warfare environments. This system provided a prototype simulation tool for planning and training medical personnel to respond to contaminated casualties in a domestic disaster scenario, such as a terrorist release of biological agents.[43] SNL and the Naval Health Research Center first collaborated on the enhanced MediSim system, which incorporated cases with multiple traumas. Both systems trained users to perform rapid assessments of the mass casualty environment and to allocate scarce resources.

APPROACH

Merging VR technology with algorithms depicting the clinical progression of the patient involved the creation of decision trees mapping the most likely outcomes for each simulated patient. These decision trees describe the initial condition of each casualty, anticipated provider actions, and their clinical impact. That impact is manifested as a sequence of changing clinical states based on the Finite State Automata (FSA), a mathematical model for representing and analyzing finite dynamic systems, organized entities that change over time with respect to a finite set of inputs. Human physiology is an example of a system, or set of systems, whose state is determined by a set of inputs: what we ingest or breathe, what injuries we sustain, what treatments we receive. Even though modeling the systems of the body and their complex interdependencies is currently beyond the scope of present day biomedical engineering, an FSA model can capture the "critical states" through which a patient passes, given (or not given) various treatments and drug therapy.

A very simple FSA model of a chest injury is illustrated in the following state/transition diagram:



In this five-state FSA, circles represent the states of the patient and are labeled with letters and systolic blood pressure. State A, C, and D represent the patient's initial state, a stable state, and death, respectively. Arrows represent actions (treatments) taken by a provider, and dashed arrows represent inaction. For example, performing a needle thoracentesis while in State A transitions the patient to State B. Performing a chest thoracostomy within 10 minutes or a combination needle thoracentesis/chest thoracostomy within 20 minutes transitions the patient to State C. Without a chest tube, the patient eventually transitions to State D. In addition, certain treatments like CPR that are inappropriate in this scenario hasten the patient's decline to State D.

The FSA model provides the logic and flow necessary for computer-based training of casualty care. Students are presented with the initial state of a patient, and their actions or inactions are recorded by the FSA. Student performance is based upon their path through the state transition diagram. The FSA model has additional attributes:

1. Models can vary in complexity from having very few states to hundreds of states, and each state may vary in the extent to which it provides medical and laboratory findings. For example, simulating an initial far-forward emergency response may simply involve

providing the patient's vital signs. At higher echelons, additional findings, test results, and a complete patient history could be provided.

2. The FSA can be made available on the World Wide Web as an application that runs within a Web browser, allowing cases to be developed collaboratively by traumatologists. They can also copy their scripted abnormal findings to other "states" to minimize data entry.

3. Using the FSA model, the subject matter expert (SME) can focus entirely on clinical content and not format because FSA-driven state engine software is physically separated from SME input.

4. Various "what-if" scenarios can be studied where the patient's outcome and comfort level varies given the availability of treatments and diagnostic services, the level of available medical expertise, changes in personnel and other resources, and changes in evacuation time.

5. The FSA can interpolate numerical quantities between the critical states of the patient, adding a greater sense of realism and facilitating continuous updates.

It is important to emphasize that the focus was on training, not simulation. Though the FSA model serves as a very basic simulator of typical human physiological response to injury and treatment or lack thereof, the model's primary purpose was to support the identification of teaching points and the critical states of selected patient conditions. Selecting permitted actions (those recognized by the system) and teaching points to emphasize for each case involved several key considerations: the various sequential paths for assessing and treating patients; situational constraints that may prevent the preferred treatment from being used, may force the responder to pursue an alternate treatment approach or to delay treatment, or may trigger an error (iatrogenic event); and the fact that students may err and attempt to remediate those suboptimal decisions or lapses. Given these influences on clinical decision-making, the most probable treatment paths were identified, including the preferred or expert path, less optimal paths, and resultant patient responses associated with those paths. SMEs also factored in the impact of time, natural injury progression, the speed at which interventions are delivered, and the failure to act further at any

point, coincident with a defined clinical state. These states were mapped as branches ending in stabilization or an irreversible progression toward death.

The Use of Teaching Points

Simulated patients were developed for our head trauma trainer with prototypical features to facilitate learning. Students have greater recall and can more easily and accurately classify prototype cases and master categories of cases when initial learning occurs through prototypes.[11] We selected patient conditions that were especially appropriate for demonstrating important teaching points. Since head injuries are complex and difficult to assess, staying alert for delayed problems, and recognizing and preventing secondary injuries from occurring (like increased intracranial pressure from a hematoma) is vital. Early and continued evaluation and tracking of injuries to identify trends and prognoses ensure more informed treatment decisions. The training system was therefore designed to teach providers two essential functions:

1. How to distinguish between the patient's superficial appearance versus the actual underlying nature and severity of the patient's condition, and the urgency for triage and stabilization. The patient's presenting appearance can be deceiving. The student may wrongly attribute the patient's deterioration to a more apparent condition when a less readily discernible condition is the culprit. Similarly, when triaging more than one case, the patient with the graver appearance visually may actually be less afflicted than the more benign appearing patient with less obvious but more severe injuries. The trainee must learn how to distinguish between the two.

2. How to identify and track trends in changing patient symptomatology in order to more accurately determine the prognosis; prioritize; treat; and, if necessary, to more effectively communicate those trends to remotely stationed medical experts for guidance. This requires repeated and frequent assessment of the ABCs (airway, breathing, and cardiac function) in order to diagnose "delayed" problems.

Patient Cases Selected

To facilitate learning in a contingency-based, experiential training environment, patient cases should be selected and developed by experienced traumatologists, neurosurgeons, and military medical specialists. These experts have had the chance to identify the most representative problems and case features, and can choose the most prototypical physiologic signs and symptoms encountered in the field.[11] In this project, representative cases with progressively complex multiple traumatic injuries were selected for prototyping to emphasize teaching points. These specific cases were chosen so that training scenarios would require successively difficult discriminations to arrive at a correct diagnosis and treatment plan. Three cases were included: a small open chest wound that develops into a tension pneumothorax; a case with multiple wounds to the head and chest leaving an alarmingly bloody open head wound and a punctured lung which also leads to a tension pneumothorax; and a closed cerebral concussion case.

The tension pneumothorax represents the least complex simulation for initiating the trainee into the virtual environment. It is a common battlefield wound in which a small penetrating chest wound causes air to be drawn into the virtual cavity between the chest wall and the lungs, enlarging the nonfunctional space. As pressure builds, the lungs are compressed and the patient begins to suffocate.[39,44] The open and closed head trauma cases were selected because they involve "distracting" injuries. These distracting injuries teach the student to see beyond the patient's immediate appearance and recognize the more clinically crucial though less clinically apparent problems, and to vigilantly monitor for delayed problems.

In the case of the open head wound and lung puncture, the head injury looks worse than it really is. It is the blow to the chest, which has punctured the right lung, that quickly develops into a tension pneumothorax that threatens to kill the patient within minutes if a needle aspiration or tube thoracotomy (chest tube insertion) is not performed. Teaching point: Will the trainee be distracted by the head injury, assume this is the cause of the patient's deterioration, and miss the delayed breathing problem that ensues?

In the cerebral concussion case, the closed head wound does not look severe but is actually critical. In addition, the trainee may initially overlook a life-threatening breathing problem that requires immediate intubation. Once a jejunostomy tube (J-tube) is successfully inserted, the

patient appears to stabilize. However, if the student fails to quickly perform a neurologic assessment, recognize that severe neurologic damage has occurred, and administer an intramuscular injection of diazepam, rapid deterioration leading to a seizure and then death occurs within minutes.

TRAINING SYSTEM COMPONENTS

EXGEN was originally conceived as a single, self-contained training product. However, during development it became clear that the system would be more useful if its library of cases could be integrated with other types of training interfaces and devices. In this project, a client-server system was developed that split the simulation component from the user interface. This modular system provided for reuse of algorithm-based cases on a host of training interfaces—PCs, VR systems, and electronically controlled mannequins. The final system included a VR interface incorporating devices for immersive viewing (goggles), for tracking the trainee's position and posture, and devices enabling the trainee to manipulate virtual objects; an audio-enhanced flat screen interface presenting the same patients on a PC monitor; the Patient and Scenario Authoring Tool for capturing SME information; the FSA-based transformation of SME case information into patient state algorithms; and the StateEngine, a detached server for interactively receiving, processing, and transmitting data and providing the algorithm-based intelligence to drive the VR and PC interfaces.

Virtual Environment

SNL's VR trainer uses a headmounted display to immerse the user in a high resolution virtual environment consisting of local terrain, the trainee's virtual self, and the virtual casualty. Trainees are represented within the virtual environment as full graphical figures called Avatars who provide a high-fidelity representation of the actions and motions of the trainee. The casualty consists of a virtual human manifesting the symptoms of the wound being modeled as well as the changes brought about by the intervening medic. The system provides feedback to the user on the state of the casualty and on the status of the procedure being performed.

VR interface. Virtual reality system components have been well described by Stansfield.[45] Trainees wear a head-mounted display that has the appearance of goggles and displays the dynamically changing environment on a tiny monitor inside the goggles. A set of four position

trackers are placed on the trainee's head, lower back, and each hand. These trackers transmit information about the user's position to the display driver which in turn gives trainees control over their viewpoint and motion within the virtual world. Real-time updates of the view of objects in the virtual world are remotely driven by the position trackers. For example, the position of the user's head tracker updates the user's view of the world and virtual objects.

All four trackers update the position and posture of the Avatar. As trainees use their hands to select simulated instruments and perform clinical procedures on the simulated casualty, they see on the screen inside their goggles a graphical presentation of their hands selecting these instruments and performing the chosen behaviors in real-time on the simulated casualty. Observers, such as training instructors, can view on a full-size monitor the simulated actions of the trainee (as represented by the Avatar) as the trainee ministers to the patient.

A critical feature of the VR system is its ability to display changes in the patient's condition— the patient getting better or worse as a result of trainee actions (or inaction) and the passage of time. Both the trainee and observers can track the changing states of the patient on their respective monitors. A voice recognition component permits the student to request information and to command certain actions. The student can: ask for vital signs and then see them displayed; obtain a history by asking the patient, "What happened?"; check motion by touching a virtual limb and asking, "Can you move this?"; do a stimulus check by reaching into the supply box, grasping the pin and poking the virtual patient, asking, "Can you feel this?"; and perform an ocular motility test by commanding the patient to "follow my finger."

The Avatar and virtual objects. Trainee position, posture, gesture, and body language are all represented to some degree of fidelity by the Avatar, using an avatar driver. These simulated behavioral components are updated at near real-time to reflect the immediate actions of the trainee. Several techniques are used to translate data input into simulated behavioral components that accurately mimic actual user behavior. First, motion study (kinematic) solutions (possible behaviors) are generated using the inputs from the four position trackers. A heuristic problem-solving technique is then applied to reduce the number of possible solutions down to the most reasonable one. This technique is based on knowledge of the human body and of the probable motions of limbs—where an elbow is more likely to be positioned when a user is waving. For certain motions that require fine manipulations, the Avatar acts semiautonomously, without

reliance on the trainee's actual movement, by using prerecorded information known to accompany a given motion. For example, when a user reaches for and touches a virtual object, a hand posture is automatically selected to correspond with a posture suitable for grasping the selected object. Similarly, the virtual objects also contain knowledge to aid the user. When the object is touched it then places itself appropriately in the Avatar's hand (eg, a syringe places itself between thumb and forefingers, gloves place themselves on the user's hand) or on the patient's body (eg, a cervical collar grasped by the user and moved to the neck region automatically inserts itself behind the patient's neck).

Trainee (Avatar)—virtual patient interaction. In responding to the user, the virtual patient speaks, grunts, and ouches as a result of integrated audio sequences. The patient makes case-appropriate movements or displays changes in appearance (eg, eye movements in response to a light pupillary reflex check or skin color change in response to a capillary refill check), and changes in pallor due to clinical deterioration, like becoming cyanotic. Again, the student is performing assessment and treatment actions directly on the virtual patient using virtual medical instruments, or is failing to perform these indicated actions and seeing the patient improve or worsen as a result.

VR Assessment and Treatment Features

Primary assessment. The trainee can select diagnostic options to conduct a primary assessment. This first stage of triage is carried out for all injury types.[39] Primary assessment includes an evaluation of the airway, breathing, circulation, disability, and wound exposure. These include checks for, respectively, obstruction/foreign objects; signs of respiratory distress; pulse, blood pressure, or capillary refill problems; consciousness, responsiveness, and normal reflexes; and wounds on the body by conducting a visual survey. Armed with this assessment information, the trainee can diagnose the patient's condition and decide what interventions to apply to stabilize the patient in preparation for evacuation. In the tension pneumothorax case, findings indicative of this condition include respiratory distress, increased breathing rate, an absence of breath sounds on one side of the chest, a drop in blood pressure, increased capillary refill time, and eventual loss of consciousness.

Intervention. The critical tension pneumothorax intervention is a needle aspiration, in which a needle is inserted into the chest and trapped air is drawn out so the patient can breathe freely. Findings that indicate the intervention was successful include increased level of consciousness, improved vital signs, and improved breath sounds. The VR trainer incorporates a dynamic casualty model that manifests these symptoms. If the trainee does not properly diagnose and then treat tension pneumothorax, the virtual casualty expires. If the trainee is able to successfully perform the assessment and intervention—to diagnose tension pneumothorax by performing the correct assessment procedures and drawing proper diagnostic conclusions, then performing a needle aspiration—the virtual patient displays signs indicating that treatment is working and eventually stabilizes. Performance time is also crucial. If the trainee does not act rapidly enough, the patient dies even if the correct actions have been taken.

CONCLUSION

In this project, a VR simulation trainer was developed to teach combat forces and medical personnel to respond to head trauma and multiple injury casualties in the field. This contingency-based, experiential training system builds cognitive rather than motor skills, teaching users to make quick and accurate decisions rather than teaching them how to perform procedures. Selected case simulations were configured to run in the immersive, synthetic virtual reality environment and on the more portable point-and-click PC. Such platform flexibility enables a greater range of instructional possibilities, including far-forward skills training and rehearsal.

Developers used a dynamic, mathematically based model that captures the critical states through which a patient passes, given (or not given) various treatments and drug therapy and the passage of time. Algorithms were then written to incorporate these critical state sequences and to depict associated changes in patient symptomatology, such as patient appearance, vital signs, respiratory status, gross neurological exam and neurological findings, and level of consciousness. Trainees perform assessments and interventions and watch virtual patients either deteriorate (and without intervention, ultimately succumb) or stabilize as a result of the quality and timeliness of their decisions. Users can practice repeatedly without putting patients at risk until cognitive skills are mastered. The training systems can be deployed to the field and used to maintain those skills once acquired.

We are witnessing a paradigm shift toward acute care-focused medicine. It is anticipated that first responders will be shouldering more responsibility for treating casualties in the future, in keeping with changing doctrine that requires the early and far-forward identification and mitigation of diseases and injuries. Responders will need to know and to do more to stabilize patients prior to evacuation. Increased use of telemedicine capabilities will accentuate this shift. Simulation systems provide multiple, tailored learning opportunities within a compressed period of time and without risk, thereby enhancing our arsenal of methods for preparing emergency responders to meet these challenges.

Simulation training can be augmented with a distributed learning approach to rehearse dispersed teams prior to or during deployment. In a distributed learning environment, trainees and instructors interact via a digital network from different places and at mutually convenient times. Distributed learning integrates the interactive capabilities of networking, computing, and multimedia, and focuses on student-centered training. It enables long-distance mentoring and allows us to create more effective learning experiences for trainees in an "any time, any place" train-as-we-deploy mode.

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13. ABSTRACT *(Maximum 200 words)*

Rapid and effective intervention for medical emergencies sustained on the battlefield, while rendering humanitarian service, or in a chemically/biologically contaminated environment is crucial for saving lives and limiting long-term disability. Inexperienced providers may suffer in performance when faced with limited supplies and the demands of stabilizing casualties never encountered back home in the comparatively resource-rich hospital setting. Head trauma and multiple injury cases are particularly complex to diagnose and treat, requiring the integration and processing of complex multimodal data. In this project, collaborators adapted and merged existing technologies to produce a flexible, modular patient simulation system with both 3D virtual reality and 2D flat screen user interfaces for teaching cognitive assessment and treatment skills. This experiential, problem-based training approach engages the user in a stress-filled, high-fidelity world, providing multiple tailored learning opportunities within a compressed period of time and without risk. The system simulates both the dynamic state of the patient and the results of user intervention, enabling trainees to watch the virtual patient deteriorate or stabilize as a result of their decision-making speed and accuracy. Systems can be deployed to the field enabling trainees to practice repeatedly until their skills are mastered and to maintain those skills once acquired.

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